AGN feedback and the connection XRISM-*Athena*

E. Costantini (SRON)

ARCUS

XRISM X-Ray Imaging and Spectroscopy Mission

THE ATHENA OBSERVATORY
EXPLORING THE HOT UNIVERSE

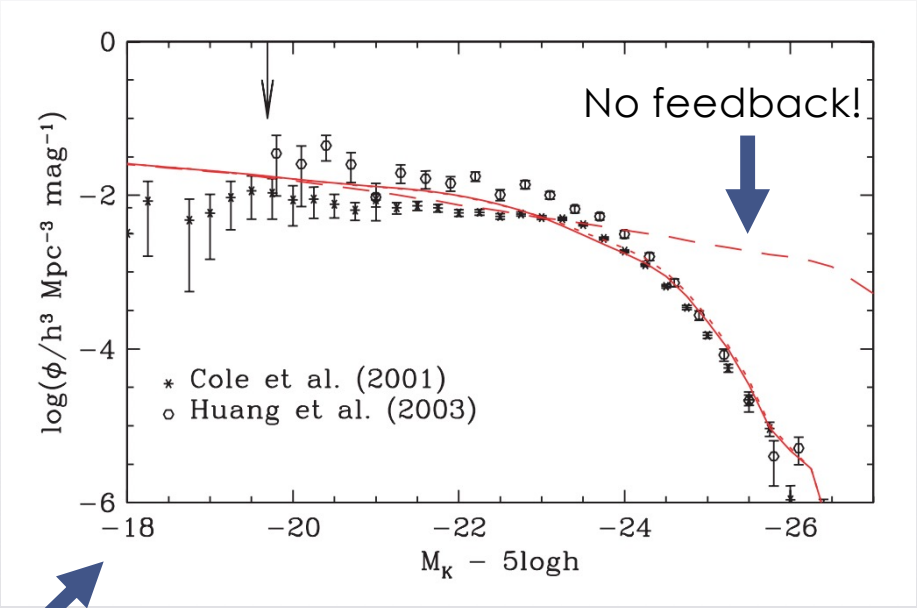
SRON
Netherlands Institute for Space Research

Outline

- Why do we care about outflows?
- How do they look like?
- What can we do about it?

Importance of outflows

- Self sustenance of the BH system (balance between accretion and ejection)
- Enrichment of the host galaxy *(Wyithe & Loeb 2003)*
- They may affect dispersal of heavy elements into the IGM and ICM *(Scannapieco & Oh 2004)*
- Contributes to M-sigma relation *(Kormendy & Ho 13)*
- Important in explaining the luminosity function: 0.5-5% *(Bower+06)*



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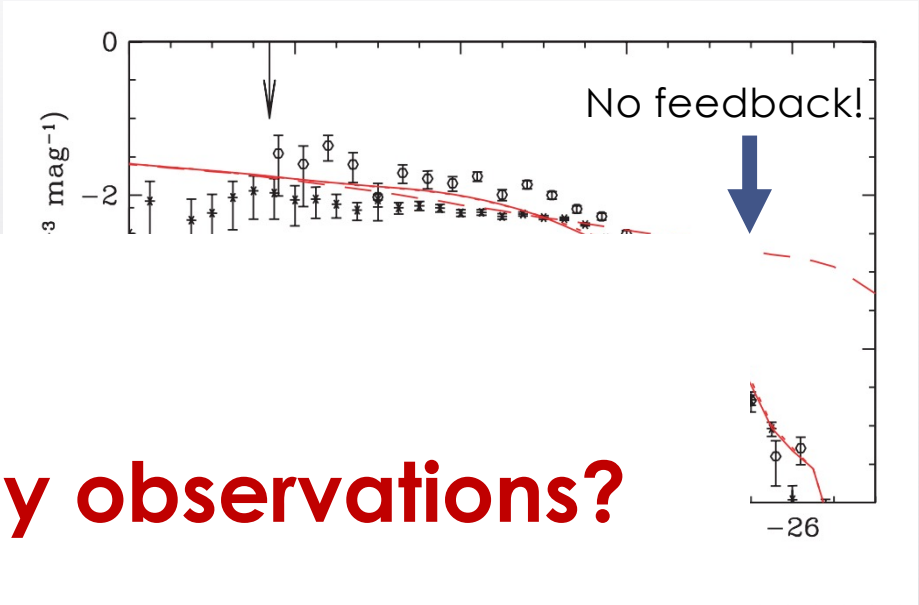


Is theory supported by observations?

outflows taxonomy

All kind of winds can coexist in the same AGN

Galactic WA
R=kpc

(di Gesu, EC+14,18
Ogorzalek+22)

...

WA
V=100-1000 km/s
R=pc

UV absorber
Line driven

(EC+07, Silva, EC+ 2018,
Crenshaw+03, EC 10,
Mehdipour+EC19, Laha+14...)

Episodic mass
Ejection
R=sub-pc
V=1000km/s

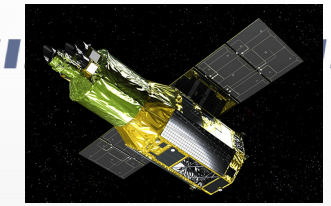
Kaastra+14...
Mehdipour+17
DeMarco+20
Kara+21

Tombesi+10...16
Gofford+13,15...
Kriss+18
Longinotti+18
Gallo+11

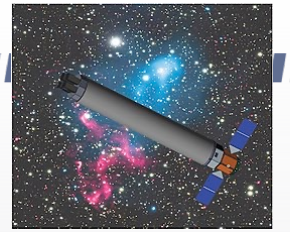
Ultra fast
winds
V=0.1c
R=sub-pc

BH

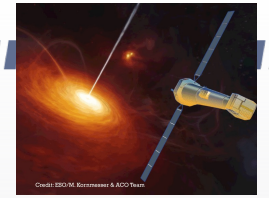
XRISM-2023

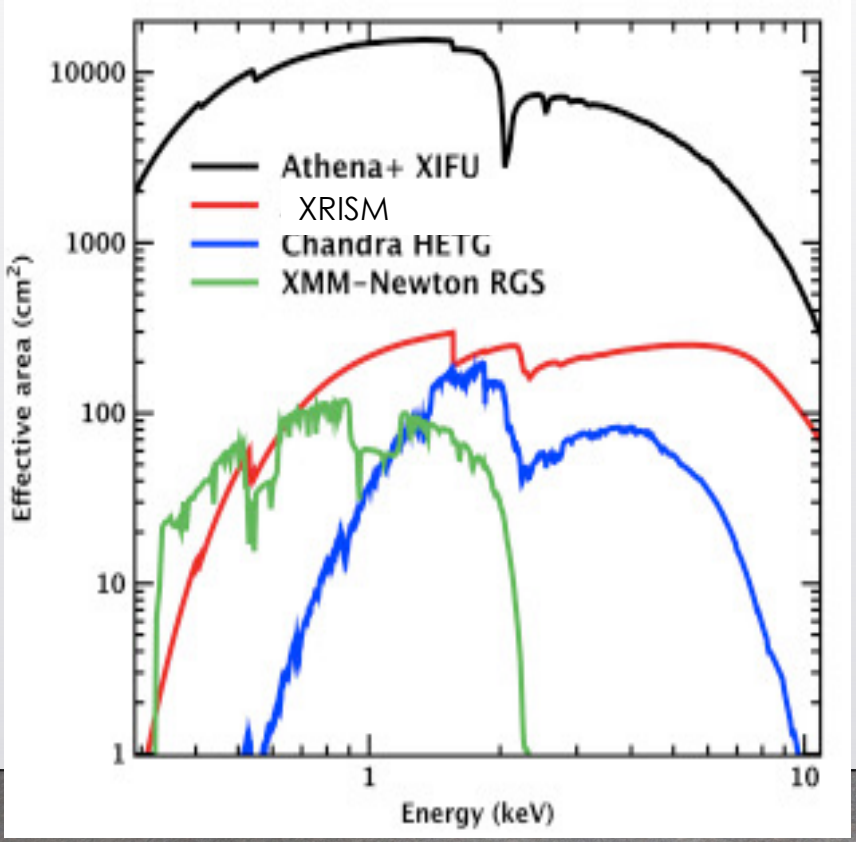


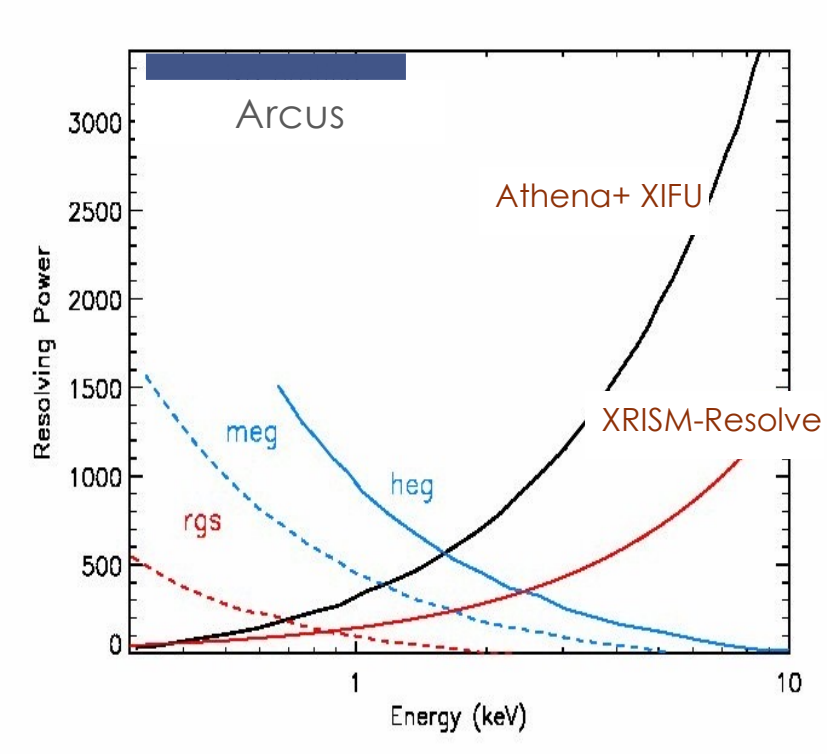
Arcus-2028?



Athena-2030s





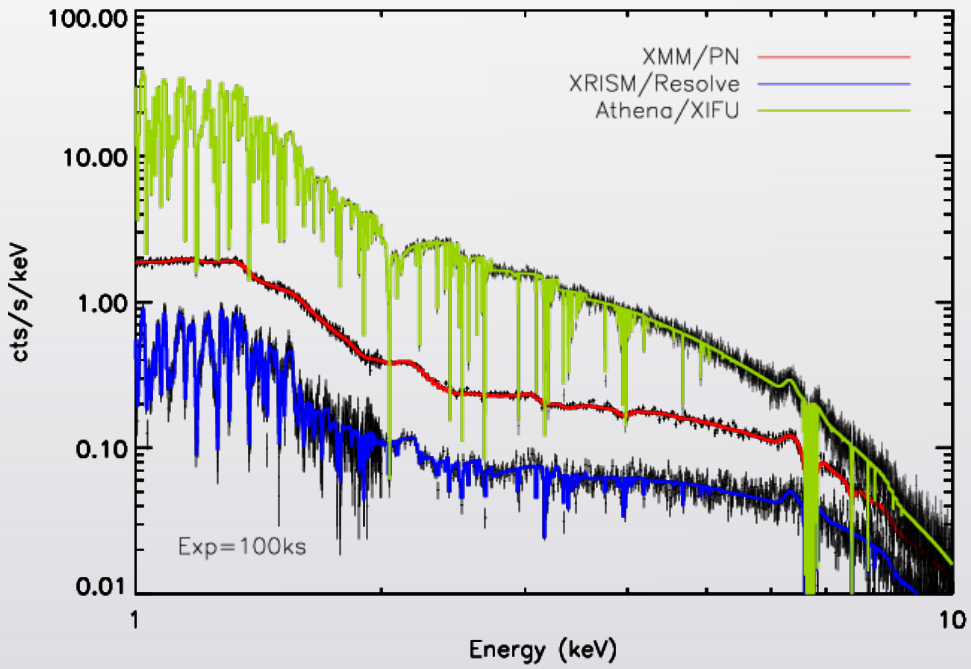


XRISM , Athena & ARCUS: a new era for outflows

- **XMM-Newton/PN: 2 warm absorbers 1 obscurer + 1 UFO + emission lines: large uncertainties on physical and chemical parameters**

- **XRISM/Resolve: unprecedented detail at medium and high energy**

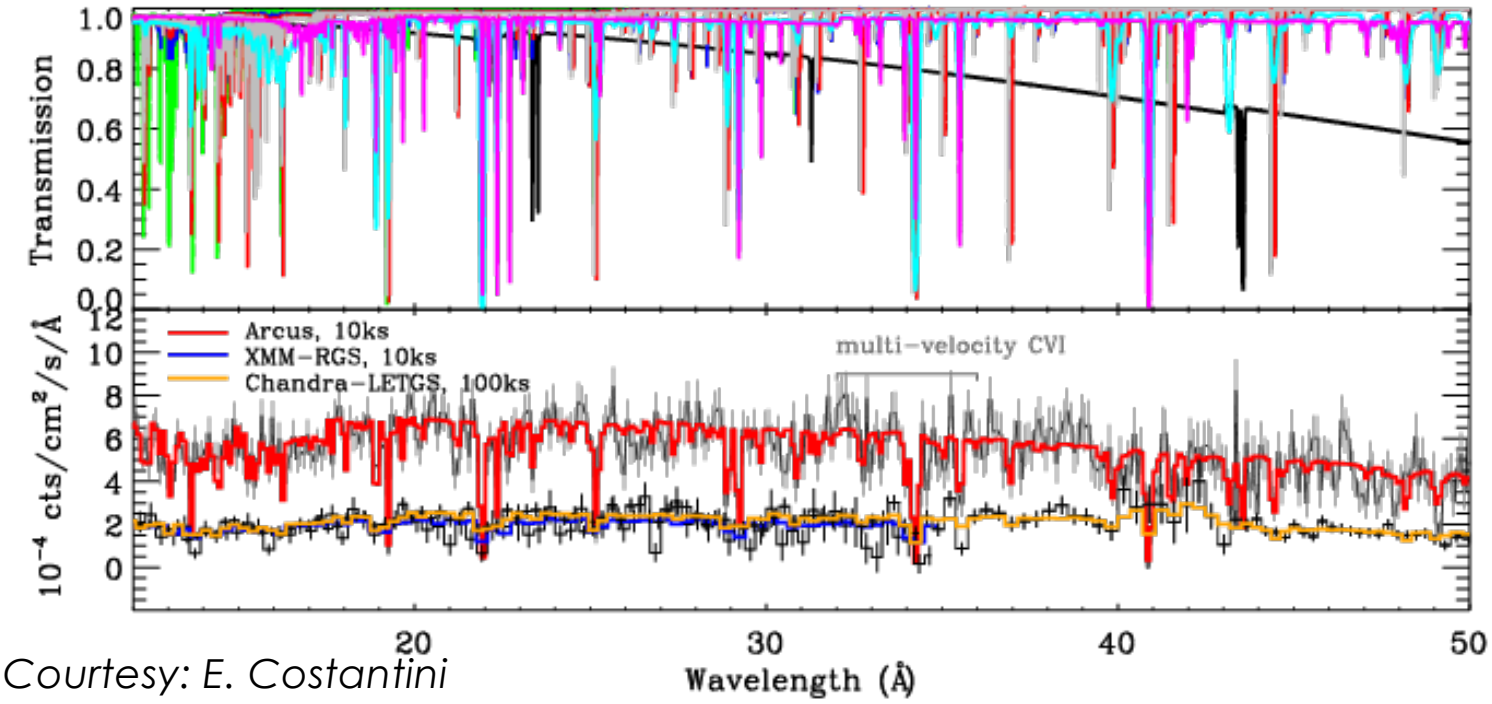
- **Athena/Resolve: resolution + effective area will access fainter fluxes/complicated regions**



Courtesy: E. Costantini

XRISM , Athena & ARCUS: a new era for outflows

- ARCUS: unprecedented resolution and effective area at soft energy and velocity resolved spectroscopy (PI: R. Smith @ CfA)



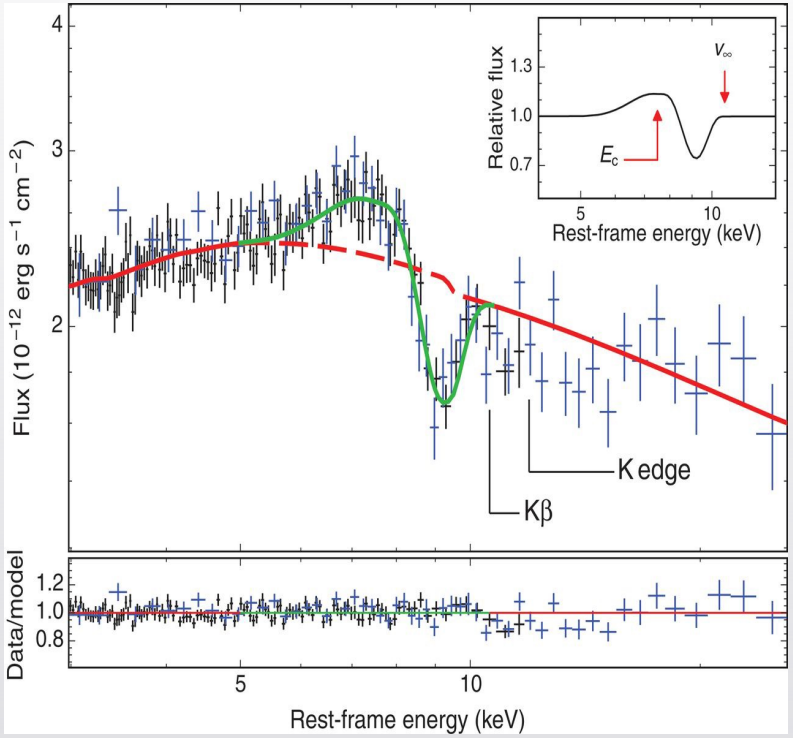
Courtesy: E. Costantini

Ultra fast outflows

Highly ionized, high column density, fast variable and very high outflow velocity v=0.2-0.4c gas
(Cappi+09, Tombesi+10, Chartas+07…)

Up to 30% of AGN may host an UFO
(Tombesi+10).

UFO



In PDS456 P-cygni profile has been detected: Outflowing gas + emission.

→Large opening angle !

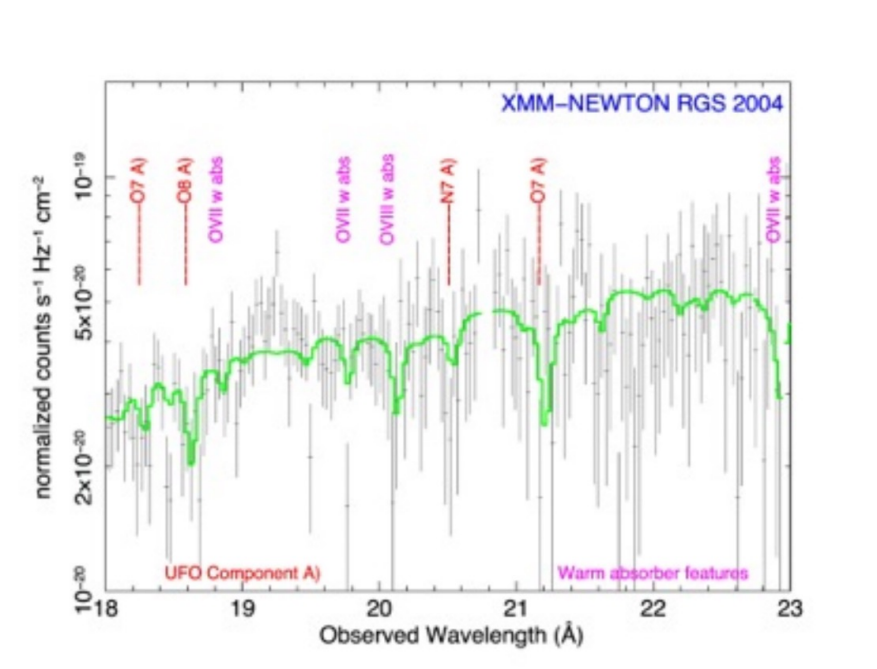
→V_{out}=0.25 c

→ L_{kin}/L_{bol}=20%!

(Nardini+15, Sci)

Low ionization UFO

- UFO-like features may be found also in low-xi gas
- Hosted by a spiral galaxy, dubbed "The milky way twin"
- Possible CO and radio counterpart
- Feedback in action?
- Is this gas accompanied by a high-xi UFO?
- Is this part of a shocked gas?

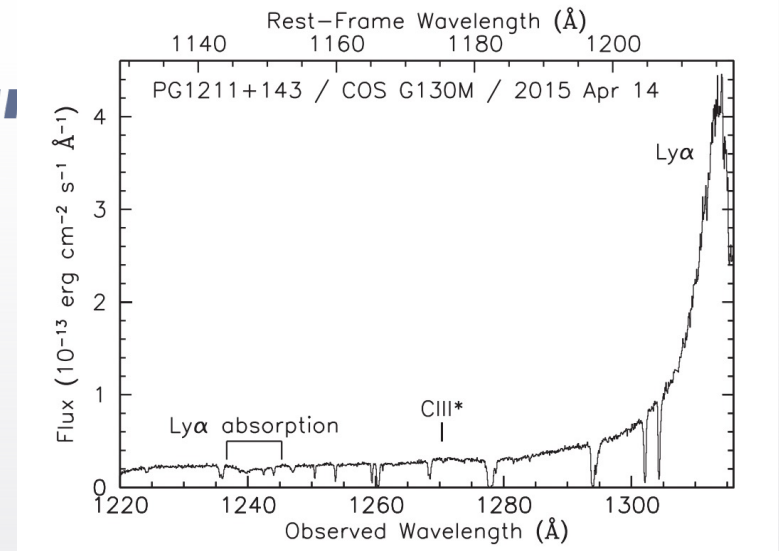


(e.g. Longinotti+18, Krongold+21, Giroletti+18)

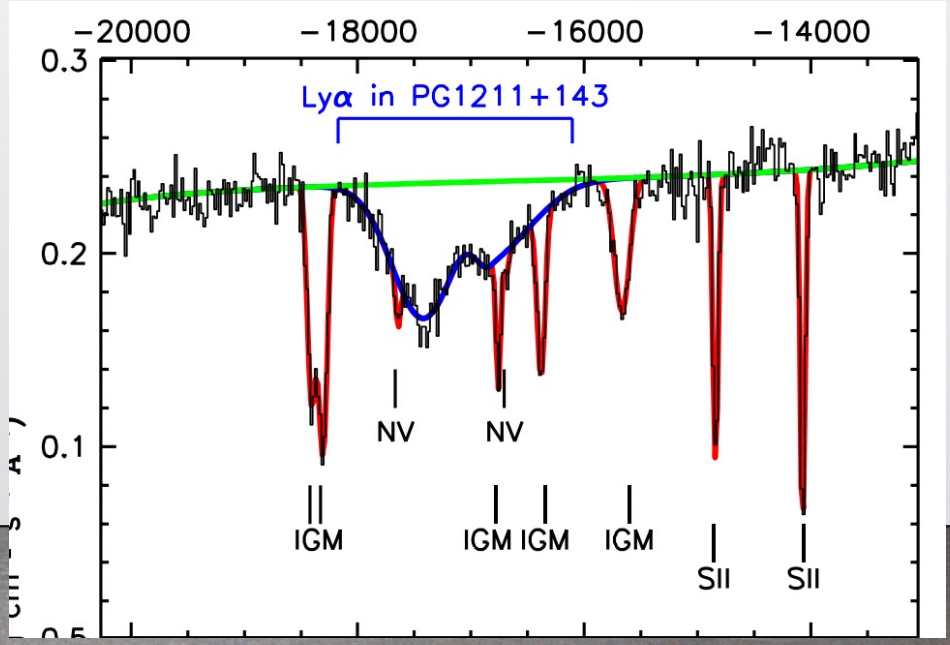
The UV counterpart of UFO

- UFO have a UV counterpart if:
  - Not too ionized
  - Simultaneous to X-rays

  (e.g. Kriss+18a, 18b, Mehdipour+22)

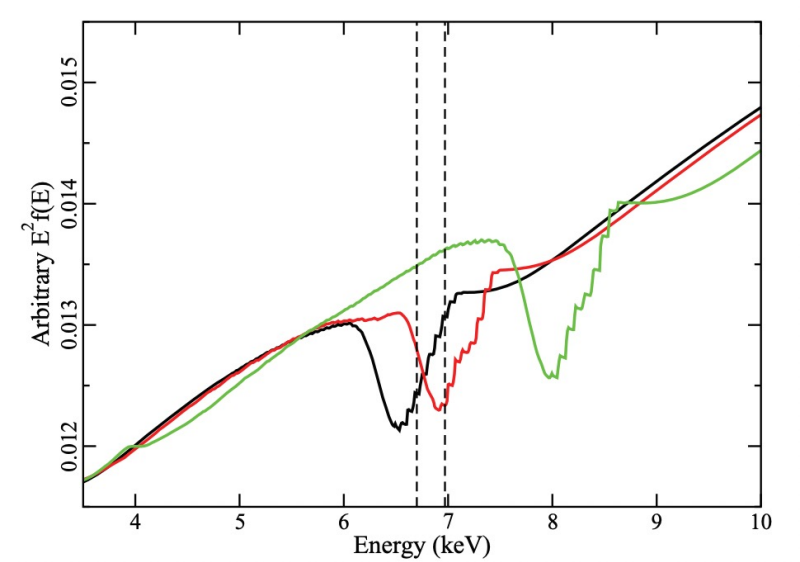


(Kriss+18a)



The alternative to UFO

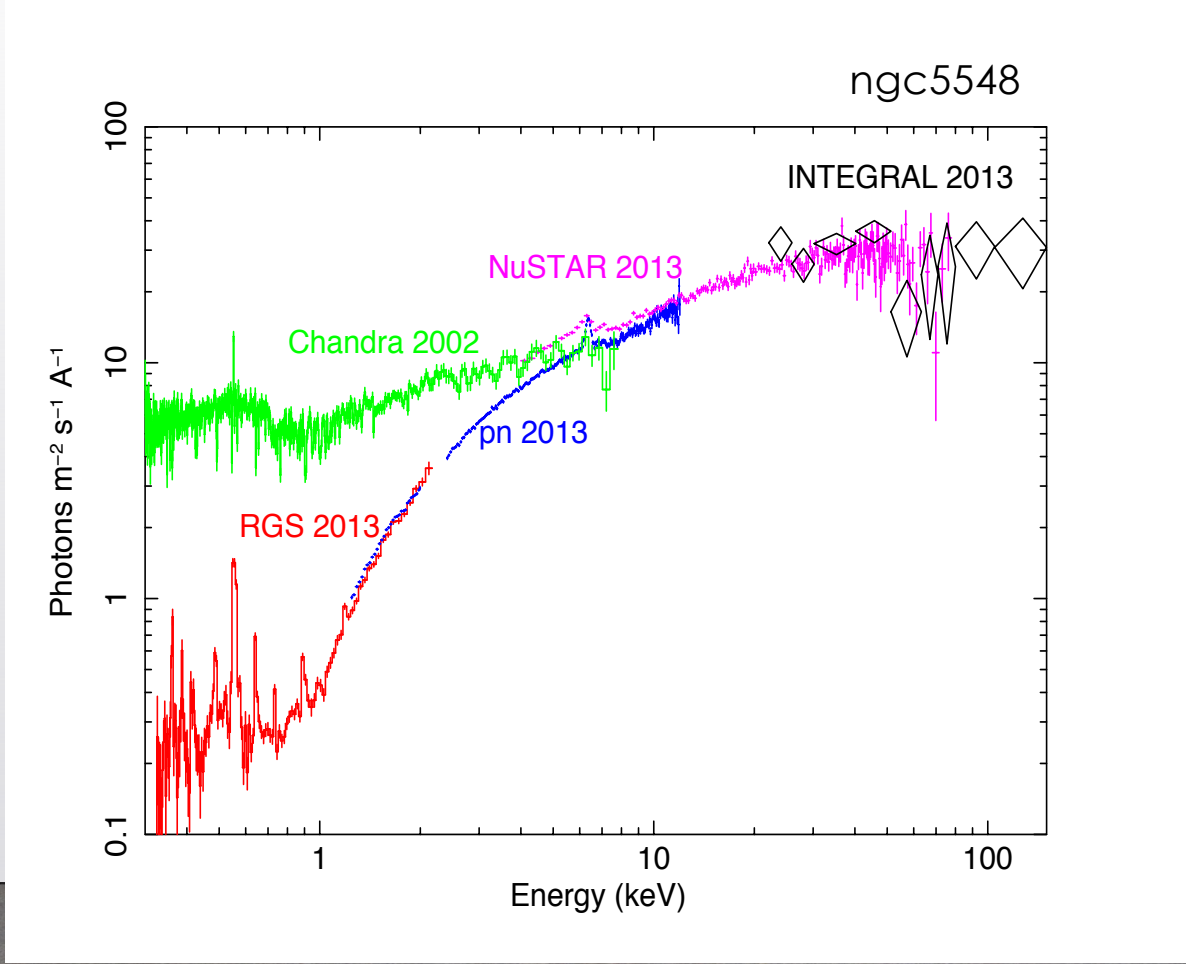
- The 6-8 keV region is crowded: emission lines, warm absorbers, UFO and reflection
- Some of the UFO features may be mimicked by absorption by relativistically smeared lines in material above the disk *(Gallo & Fabian 11, 13)*
- Possibly all features are at play *(Parker+22)*
- Only a calorimeter can help disentangling this region *(Barret & Cappi 19, Parker+22)*



(Gallo & Fabian 11)

The obscurers

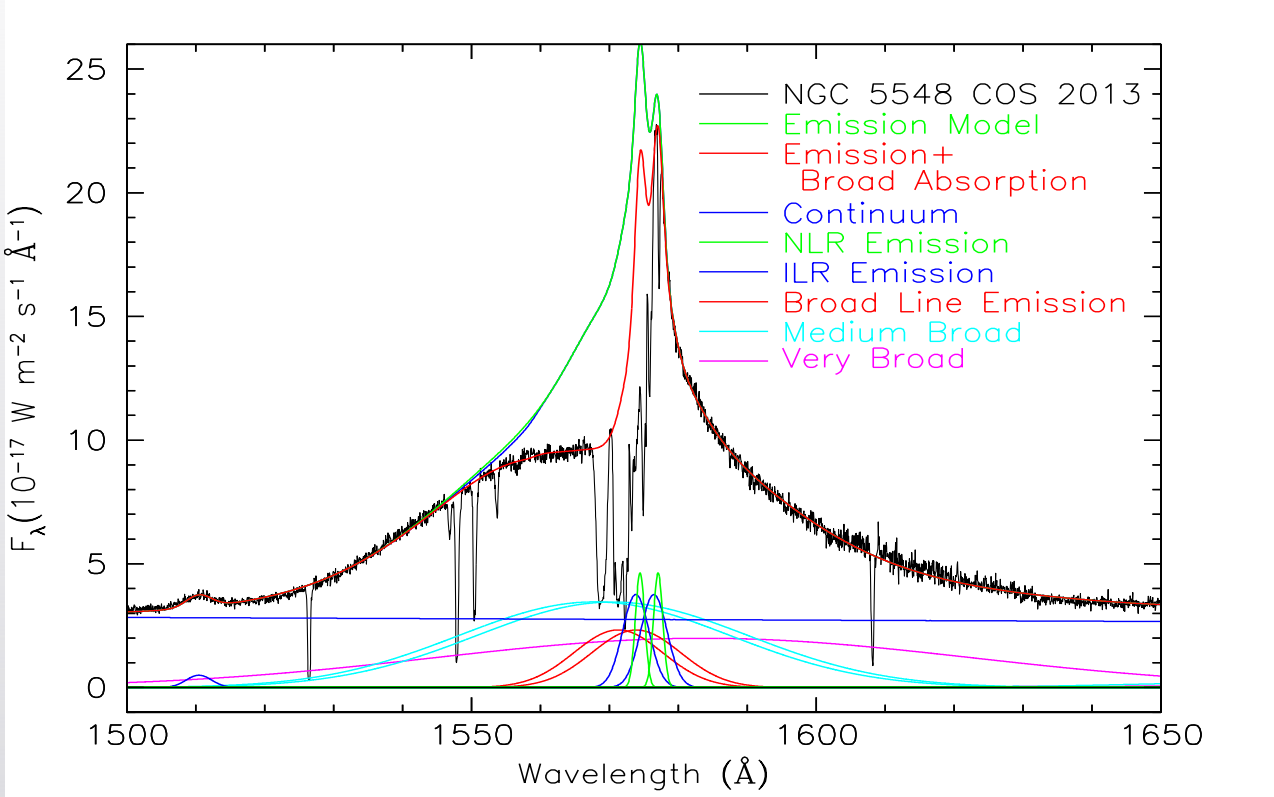
Bulk ejection



(Kaastra+14, Arav+14, Medhipour+14, Di Gesu, Costantini+15, Ebrero+16)

The UV spectrum

(Arav et al. 2014, Kaastra+ 2014, Sci)



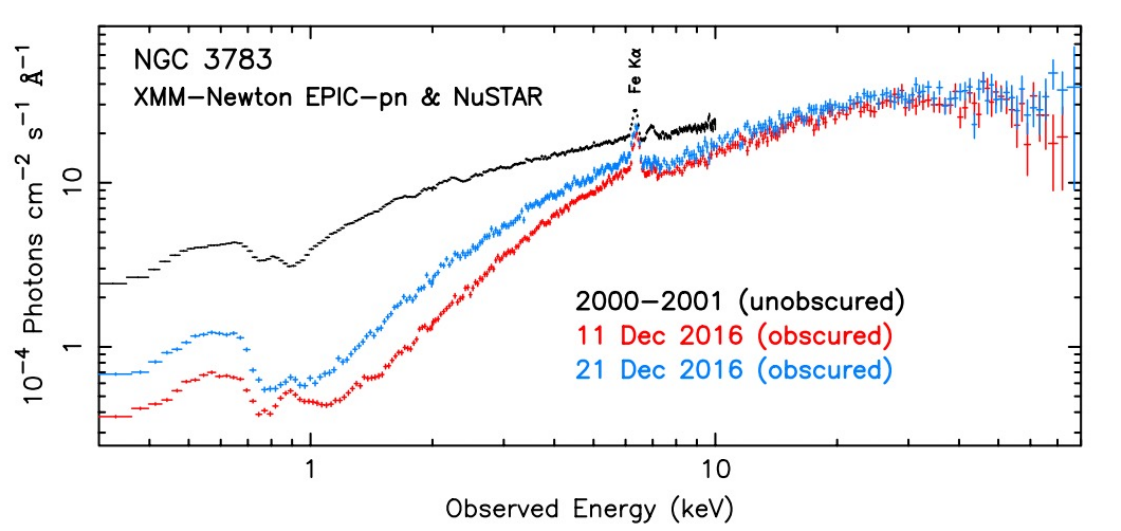
Broad UV absorption lines

A structured obscurer

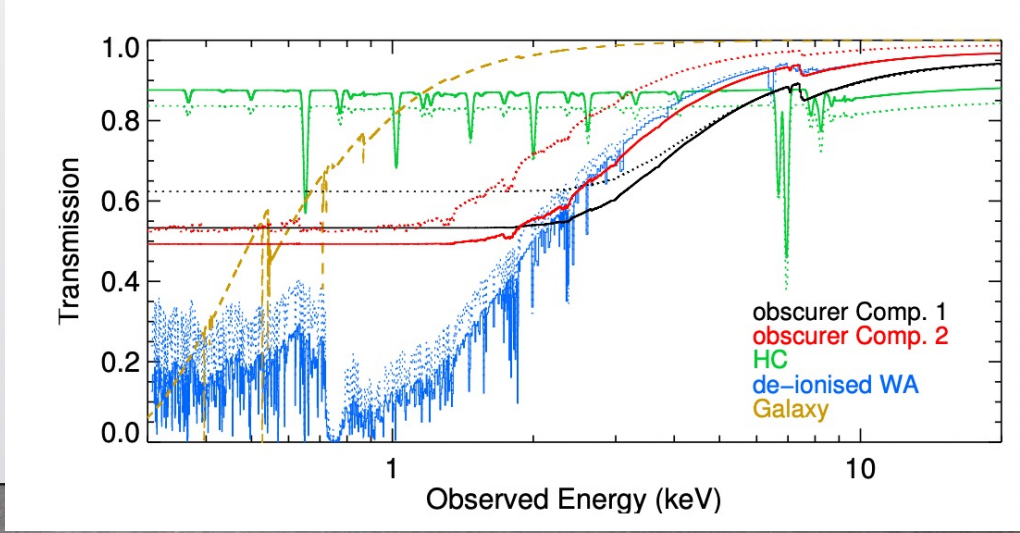
- Obscurers show different covering factors, stratification and ionization

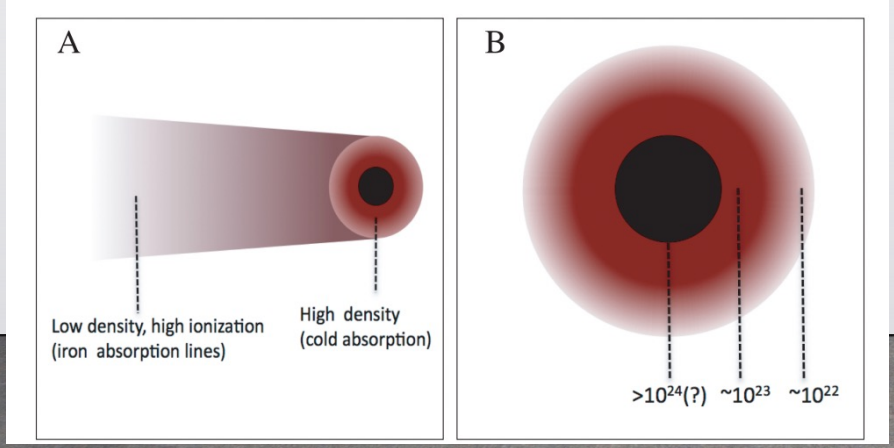
NGC5548, NGC3783, NGC3227, Mrk335, ...

- High-xi tail to the obscurer in NGC3783
- Reminiscent of Mrk766 *(Risaliti+11)*



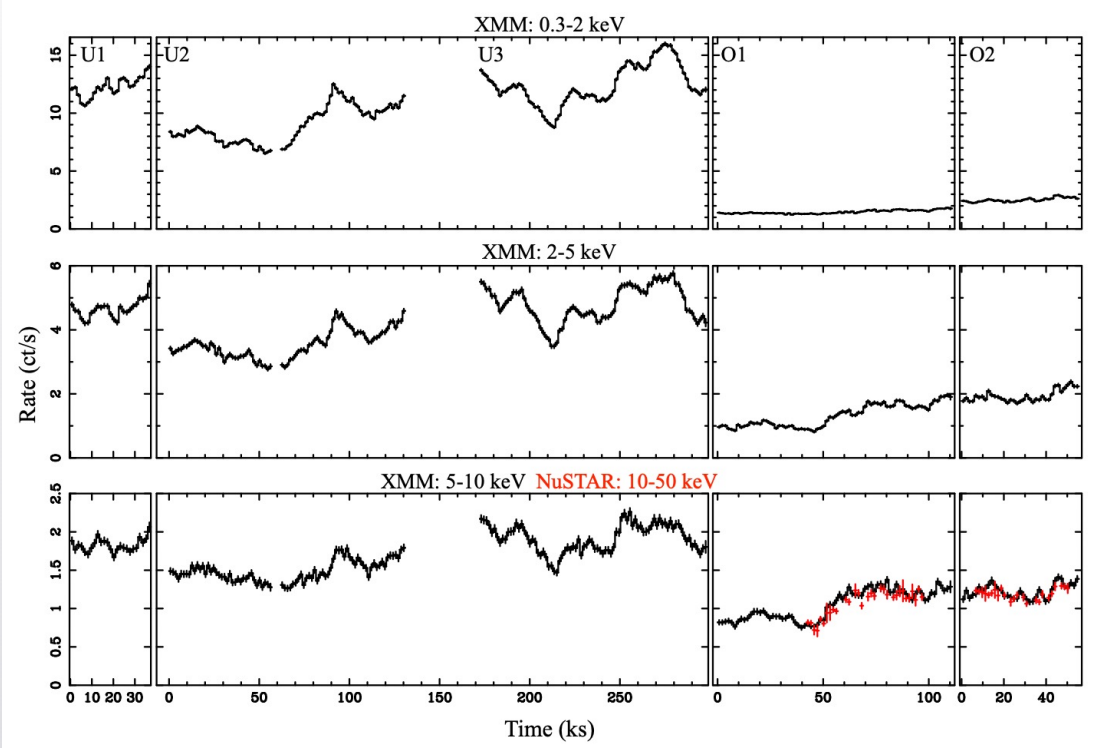
(Mehdipour+17)



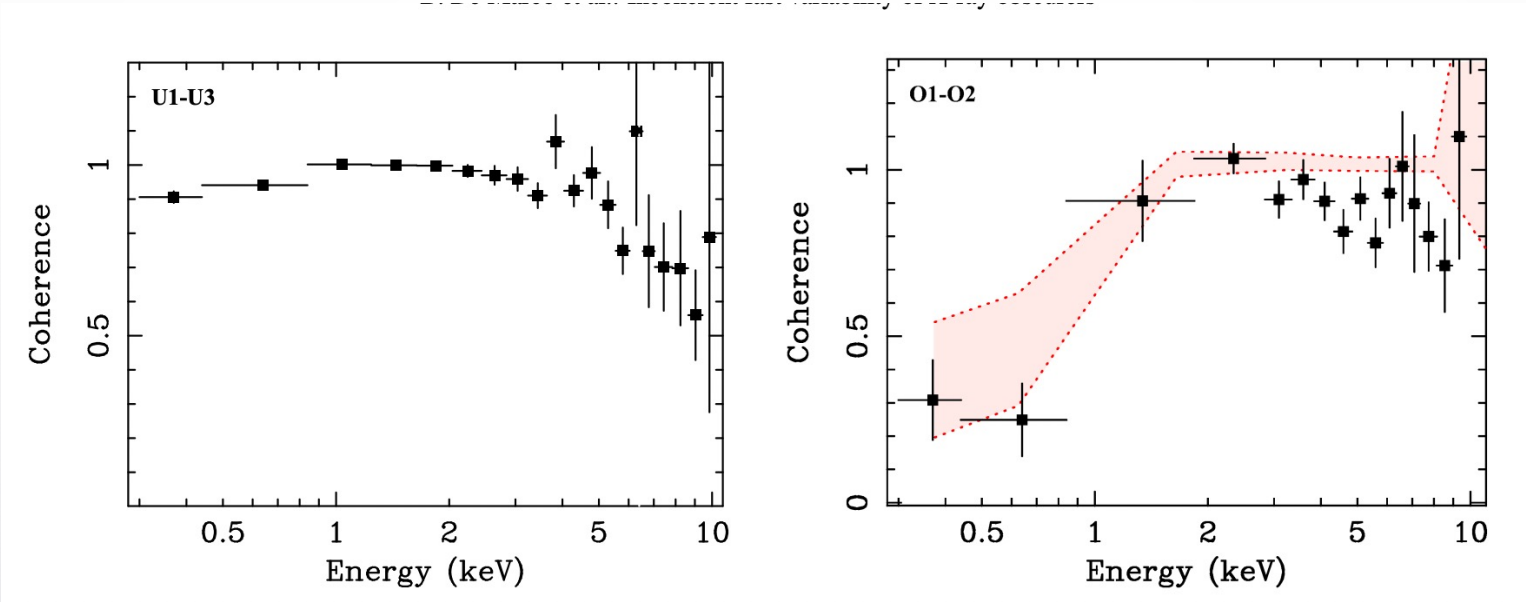


(Risaliti+11)

The timing behaviour of an obscurer



(De Marco+20)

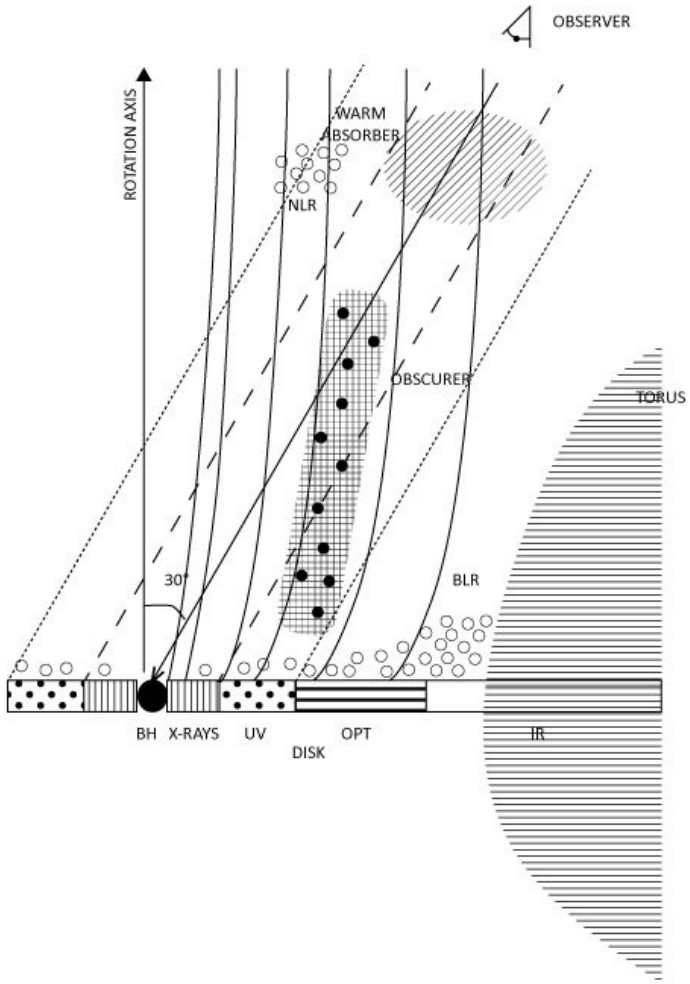


(De Marco+20)

The obscured epoch shows a highly incoherent spectrum → absortion at play
Consistent with spectral parameters of the obscurer

- UV absorption:
  → Ionization & covering factor
  - Covers the BLR
- Historical warm absorbers are ionized by an obscured SED

→ Ejection from the accretion disk?



(Kaastra+14, Sci)

all famous sources do undergo episodes of heavy obscurations!
A new element in the AGN system!

Warm absorbers

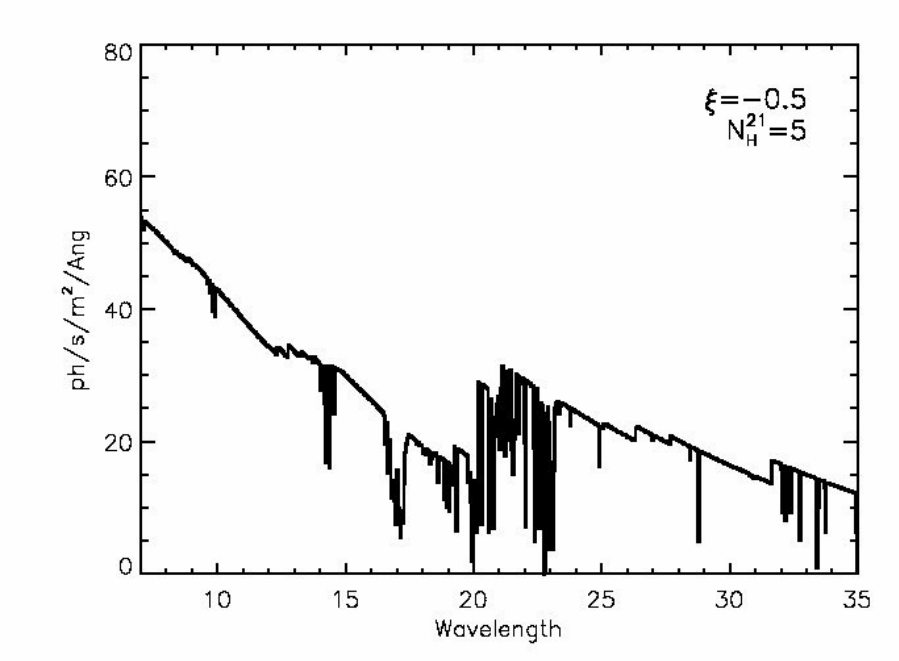
warm absorbers

- Observational parameters of WA are well determined:
  - Vout, v, NH, xi.
- Line emission (v, line ratio, covering factor)

→Connection between emission and absorption

→Stratification and thickness of the WA

$$\xi = \frac{L^{ion}}{nr^2}$$



→**Geometrical structure of the WA**

→**Connection with disk winds**

→**Connection with host galaxy**

→**Chemical enrichment of the host**

→**Launching mechanism**

The quick way for distance/density determination

Lower limit: calculate the radius at which gas reaches escape velocity

$$R \geq \frac{2GM}{v_{out}^2}$$

Upper limit: the thickness of the gas layer cannot be larger than its radius

$$R \leq \frac{L_{ion} C_g(R)}{\xi N_H}$$

(Blustin+05)

→ Classical warm absorbers would be located at torus scale!

Outflows and feedback

Mass outflow rate: $\dot{M}_{out} = 4\pi r N_H m_H C_g v_r$ $M_{sun} yr^{-1}$

Mass accretion rate: $\dot{M}_{acc} = \frac{L_{bol}}{c^2 \eta}$ $M_{sun} yr^{-1}$

Kinetic Luminosity: $L_{kin} = 1/2 \dot{M}_{out} v^2$

→Density is important for
- **AGN physics**
- **AGN relation with surroundings**

$$\xi = \frac{L^{ion}}{nr^2}$$

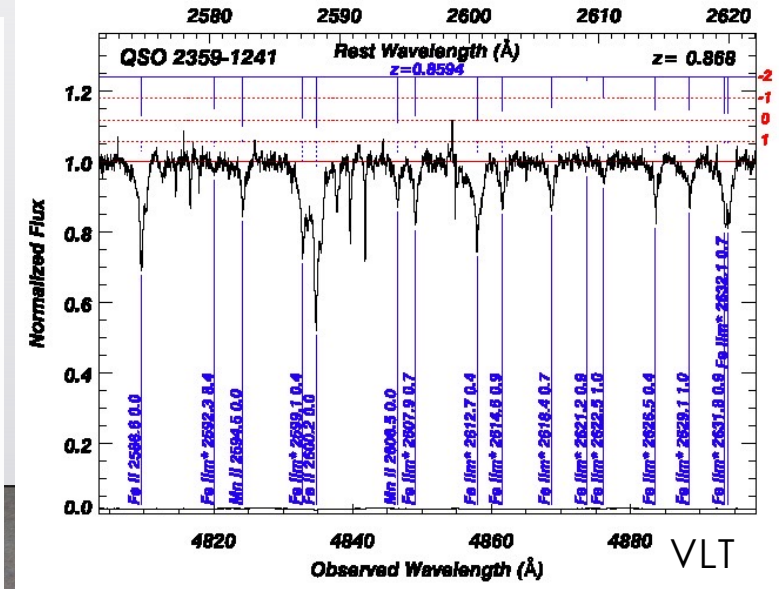
The quest for the density determination

- Metastable levels
- Time resolved spectroscopy
- Spectral timing

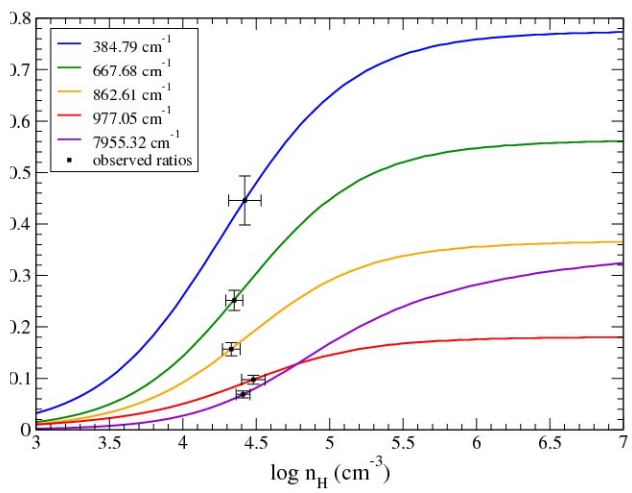
UV density diagnostic

- Metastable levels, detected in the UV: e.g. CIII*, FeII*. These are levels just above the ground level, which are populated by collisions → strong dependence on density.
- Can we do it in X-rays?

(not yet an X-ray spectrum!)



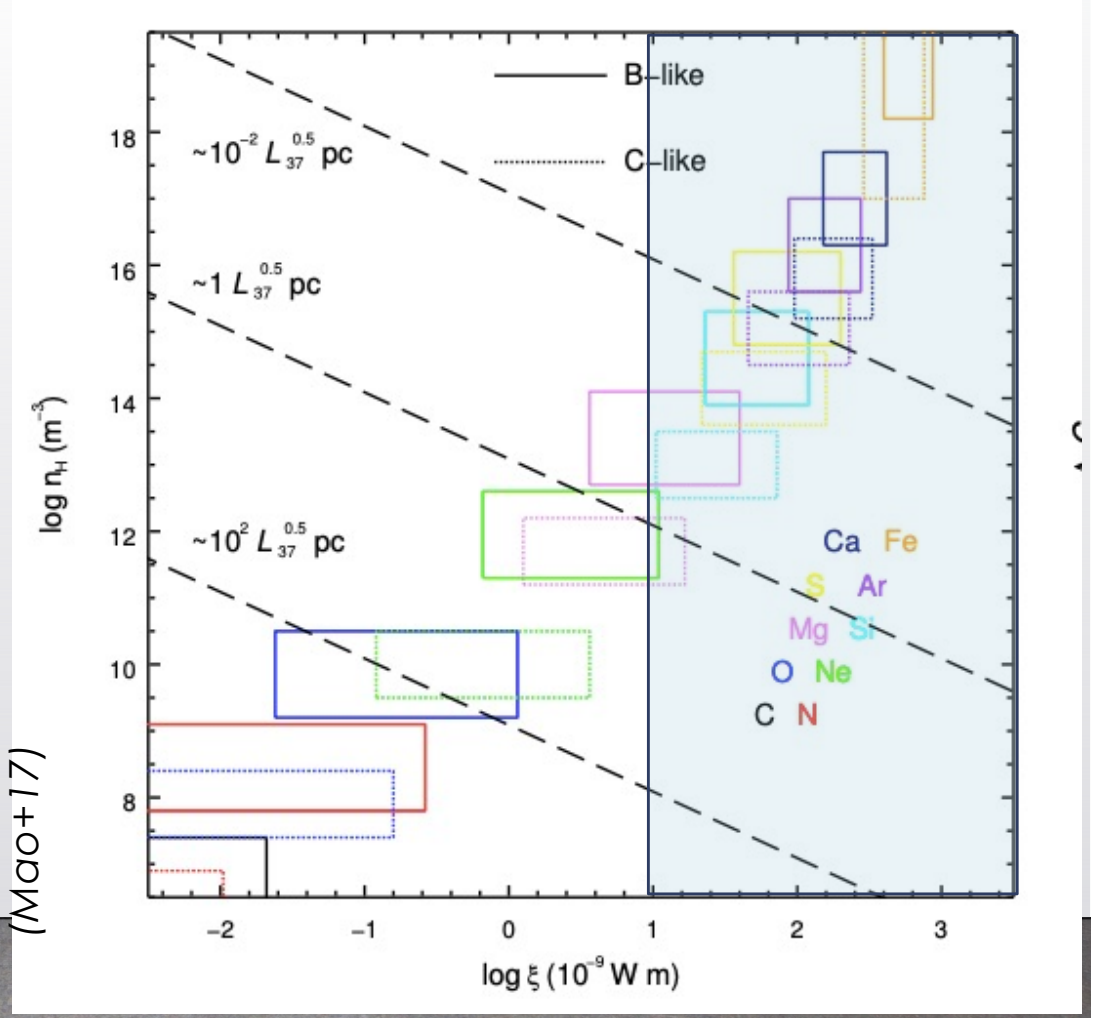
VLT



QSO 2359-1241, Arav, Moe, Costantini+08, Korista+08

Density diagnostic lines in X-rays

- Seen in X-ray binaries *(Miller+18)* and AGN *(Kaastra+04)*
- AGN metastable levels are however weak and may be sensitive to higher densities (*Mao+17*)



(*Mao+17*)

Density estimate through variability

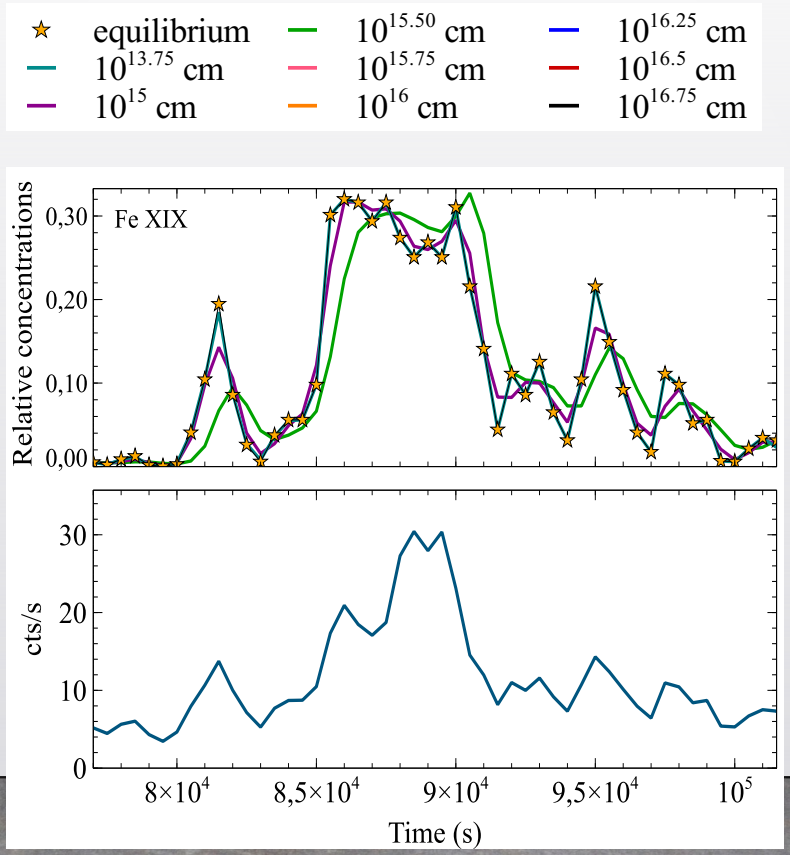
$$t_{eq}^{X^i,X^{i+1}}(t \rightarrow t+dt) \sim \left[\frac{1}{\alpha_{rec}(X^i, T_e)_{eq} n_e}\right] \times$$

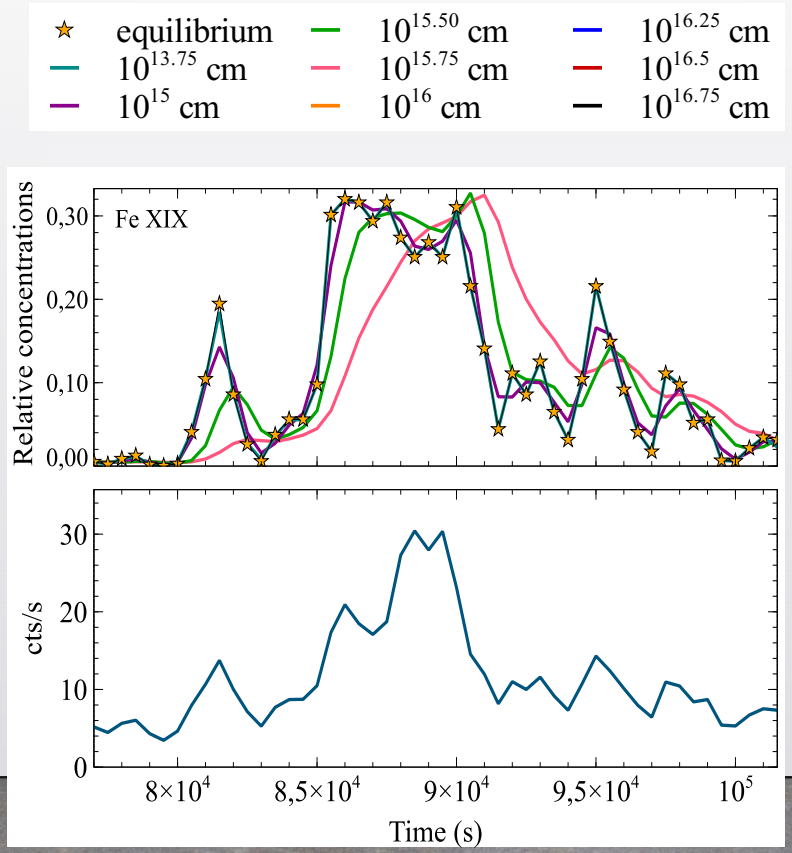
$$\times \left[\frac{1}{\left(\frac{\alpha_{rec}(X^{i-1},T_e)}{\alpha_{rec}(X^i,T_e)}\right)_{eq} + \left(\frac{n_{X^{i+1}}}{n_{X^i}}\right)_{eq}}\right]_{t+dt}$$

Monitoring the variability of the WA ionization as a function of the continuum flux is in principle sensitive to any density.

(Krolik & Kriss 95,Nicastro+99

(e.g. Netzer+02, Krongold+05, 07, Detmers+08, Longinotti, Costantini +10, Kaastra+12 Arav+15, Silva, Uttley & Costantini 16, Juranova, Costantini & Uttley 22, Rogantini+ in prep)


equilibrium
$10^{13.75}$ cm
10^{15} cm
$10^{15.50}$ cm
$10^{15.75}$ cm
10^{16} cm
$10^{16.25}$ cm
$10^{16.5}$ cm
$10^{16.75}$ cm
Fe XIX
Relative concentrations
0,30
0,20
0,10
0,00
cts/s
30
20
10
0
8×10^4
$8,5\times10^4$
9×10^4
$9,5\times10^4$
10^5
Time (s)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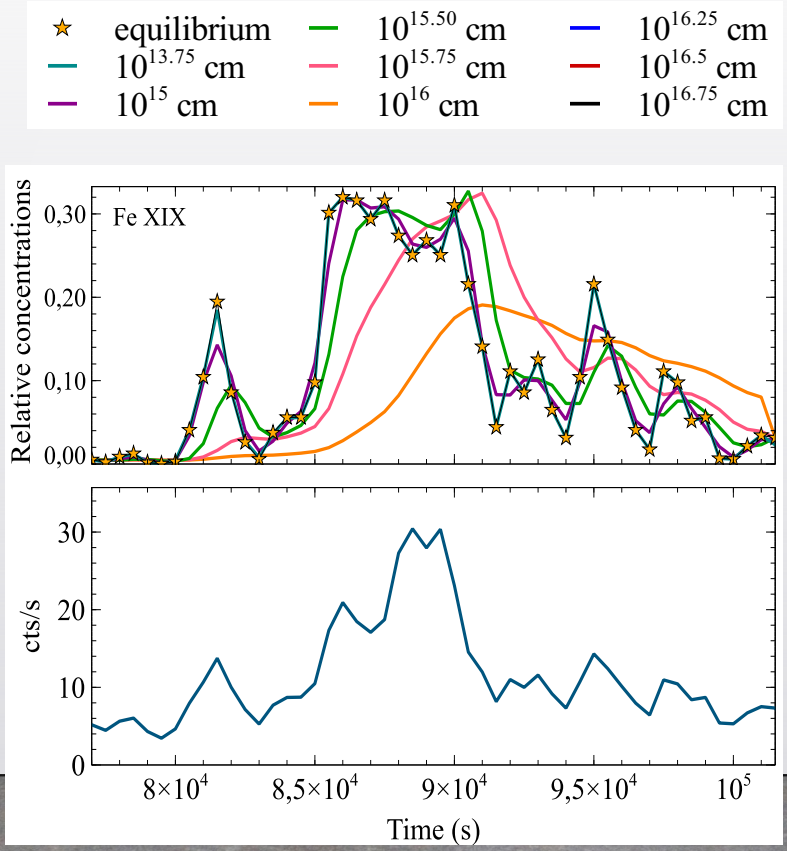
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30
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10
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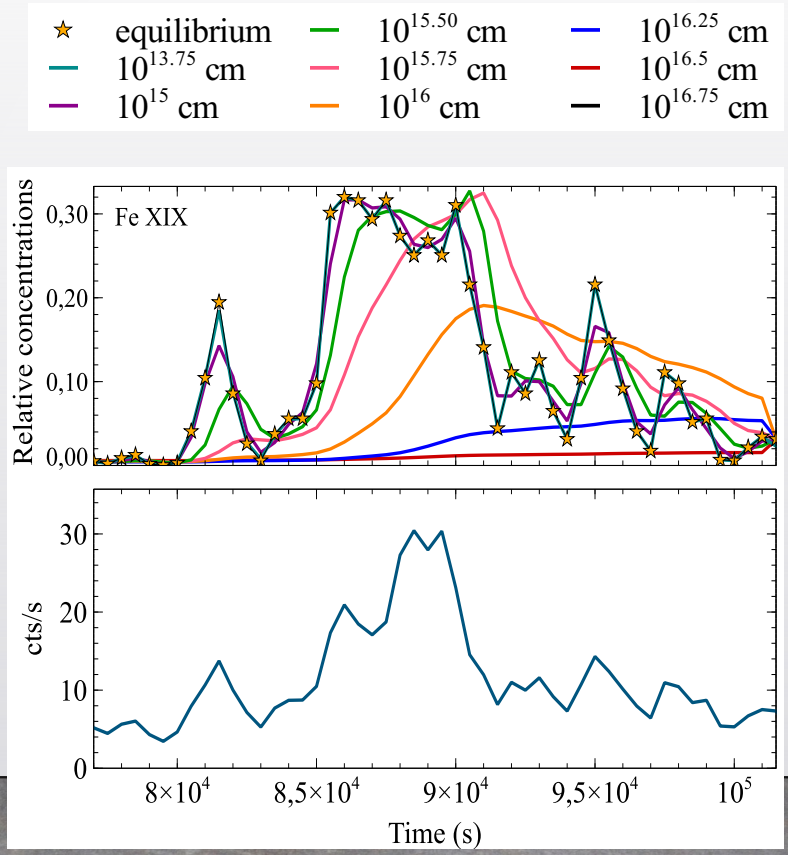
$8,5\times10^4$
9×10^4
$9,5\times10^4$
10^5
Time (s)

- There will be an ideal distance that will best fit a given set of ions, correspondent to a WA component

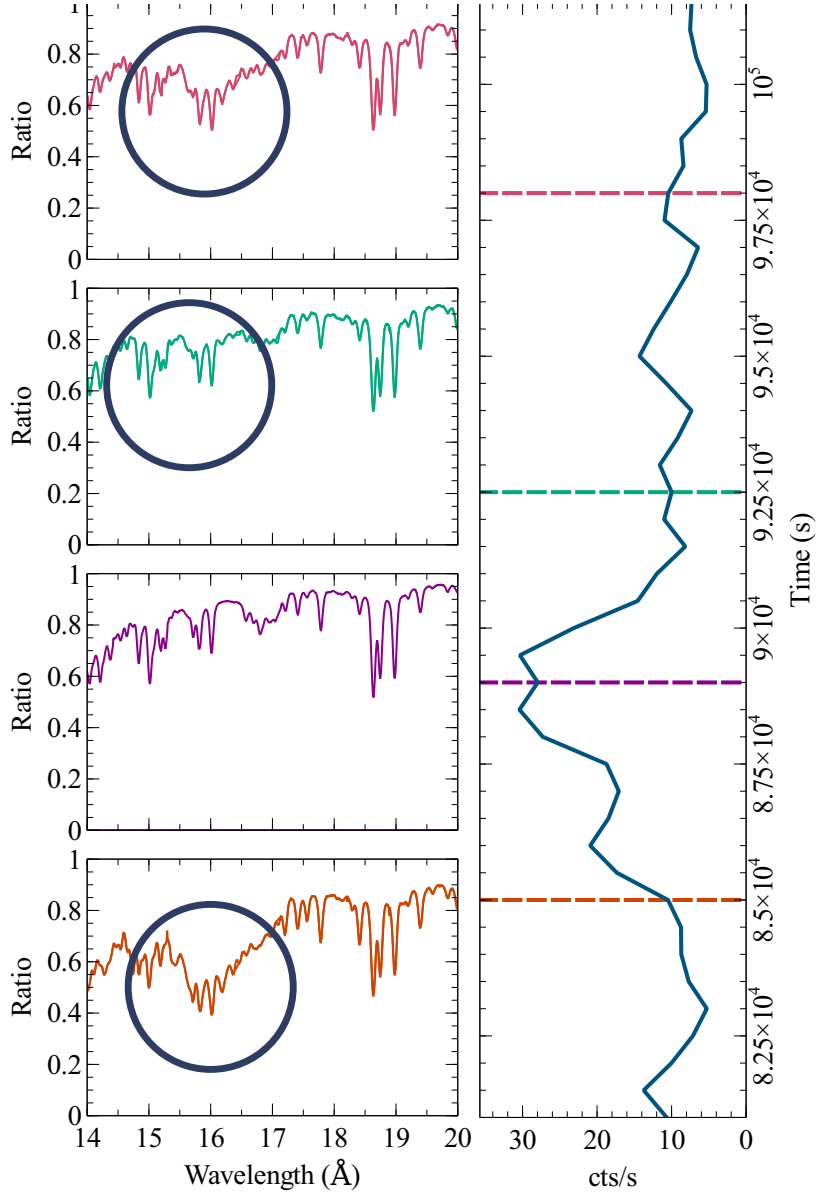


(Silva, Uttley & Costantini2016,Kaastra+12)

Time resolved spectrosocopy

The time evolution of the WA shows that the gas goes back to equilibrium After a time that depends on the gas density

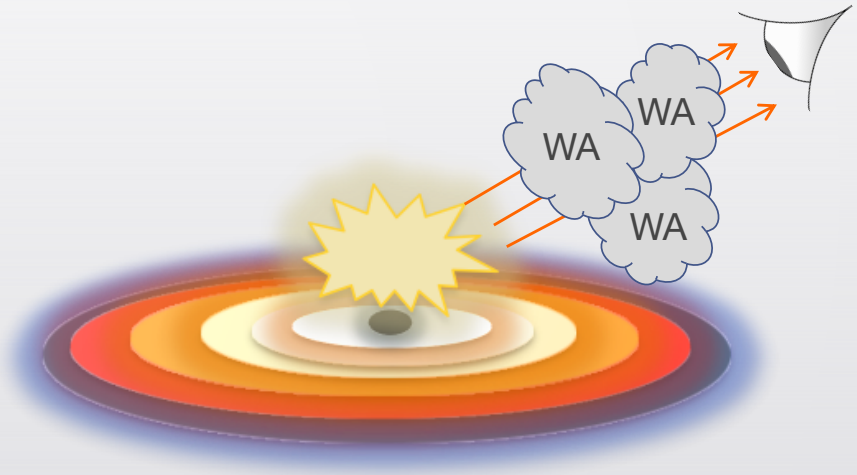
→ Great opportunity for future instruments: Athena, Arcus.
(Rogantini+in prep,)



(Silva, Uttley & EC+16)

Timing Spectroscopy

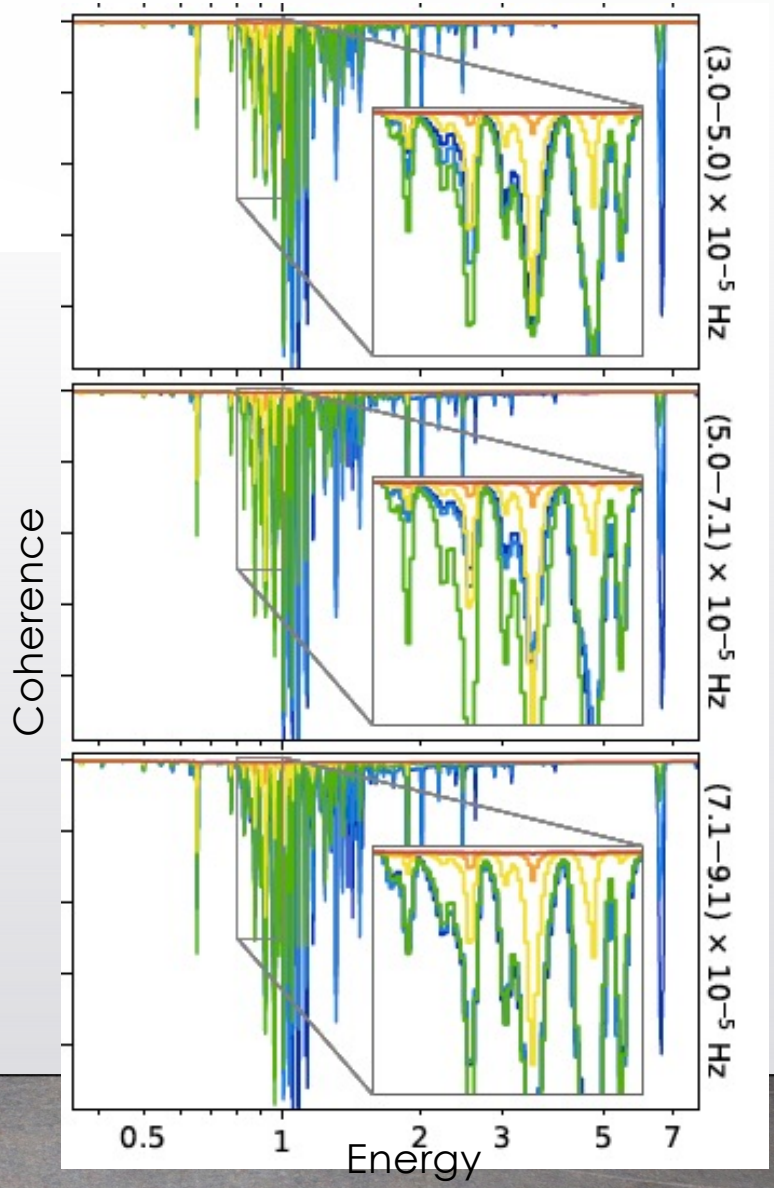
- Reverberation is widely used to study the properties of the accretion disk *(e.g. Uttley+14)*
- Warm absorbers have a quantifiable effect on time lags *(Silva, Uttley & EC16)*



(Silva, Uttley & Costantini 16)

Timing the WA

- Time lags spectra are very complex to interpret and model *(e.g. Alston+20)*
- Uncorrelated light curves (e.g. absorbed and unabsorbed) provide a coherence <1 *(e.g. De Marco+20)*
- At every frequency the coherence bears the information on the density of the gas
- Athena will be able to study and model the coherence to look for the properties of the warm absorber *(Juranova, EC & Uttley 22)*



(Juranova, EC & Uttley 22)

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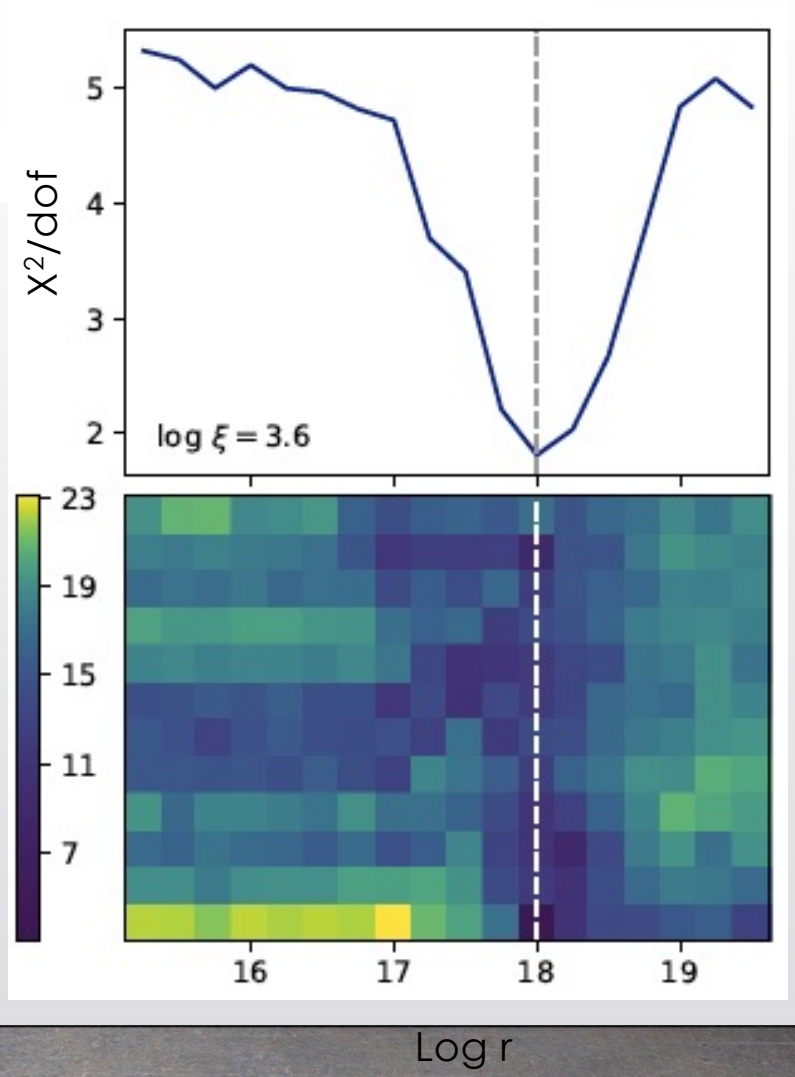


(Juranova, EC & Uttley 22)

The oddball

(Costantini+07, Silva, EC+ 18, Rogantini, EC+22)

→Long term variability:

- Ionization changes in a random fashion
- The 2 components change together in xi
- ~Same outflow velocity since 1997!
- N_H changes (factor > 6)
- No radiation pressure equilibrium

→ Short term variability:

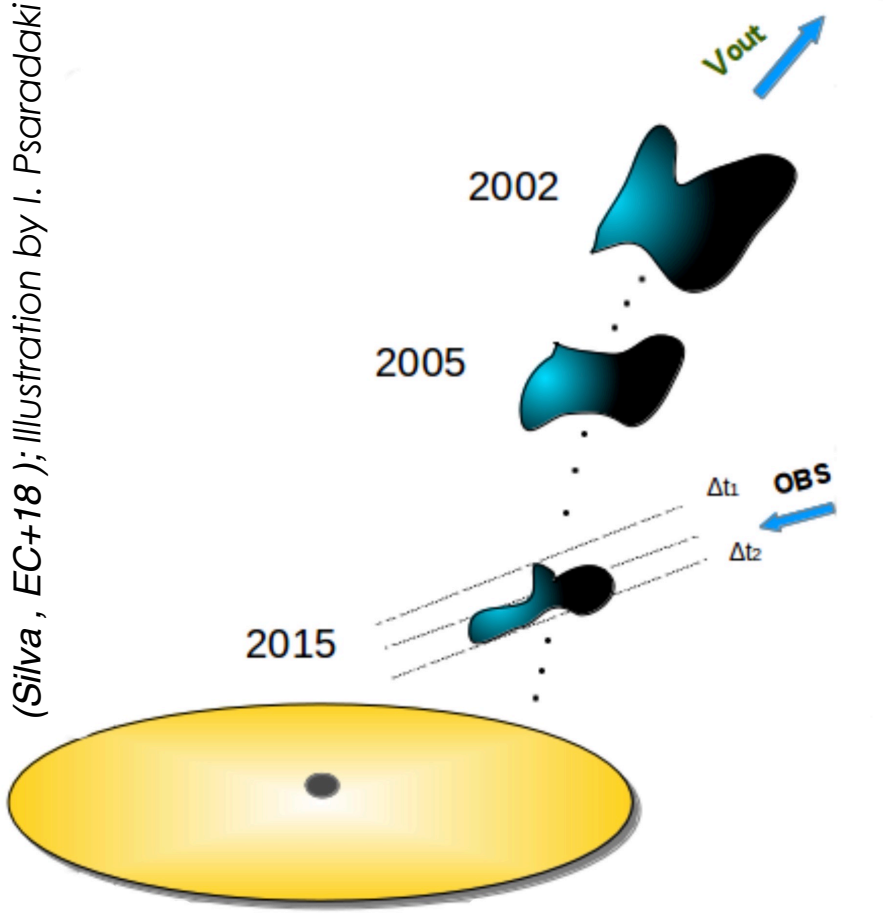
- Log-xi does not change
- NH increases when flaring?

ORIGIN AND GEOMETRY OF THE OUTFLOW: A STEAMING BOAT

(Costantini+07, Silva, EC+ 18, Rogantini, EC+22)

- Clumpy outflow driven by radiation pressure
  (Mehdipour+in prep)
- High and low ξ gas are two faces of the same gas

(Silva , EC+18); Illustration by I. Psaradaki

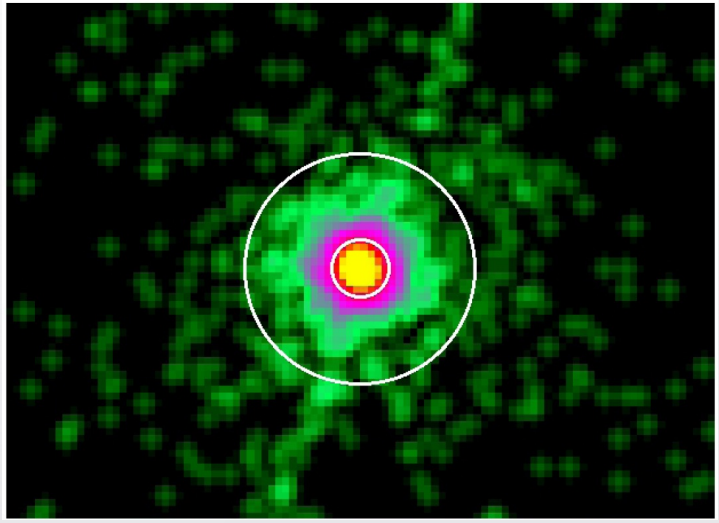


Galactic WA

Kpc scale winds

Common in BAL QSO, but normal quasars?

- **UV-X-ray simultaneous SPECTROSCOPY observation of 1H0419-577**
  - → **Density determination for the UV/X-ray absorber! Through metastable levels**
  - → **Distance! kpc scale (3 kpc) !**
- **Discovery of an X-ray ionized absorber at kpc scale**
- relic of a nuclear fast wind? → feedback in action in the host galaxy!



(Di Gesu, Costantini et al 2013, 2017)

- **Chandra IMAGING follow up:** confirmation of kpc soft X-ray emission!

Feedback budget

$$\dot{M}_{out} = 4\pi r N_H m_H C_g v_r$$

	NH	R	v
Torus absorber	✗	✗	✗
BLR/disk ejection	✓	✗	✗
Galactic wind	✗	✓	✗
Ultrafast outflows	✓	✗	✓

Conclusions

- AGN can host multiple outflows
- Some of them may be important for feedback

- The future
  - Timing and time-resolved spectroscopy
  - Metastable levels
  - → Feedback
  - → Geometry
  - → Launching mechanism